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The Iron Age iron slags of Maastricht – Randwyck: processing or production?

Stijn Arnoldussen

Keywords: Iron production, smithing, Early/Middle Iron Age, slag, metalworking

Introduction: smelting versus smithing: the Netherlands' earliest Iron working?

From the 8th century BC onwards, evidence for the presence of iron artefacts in the Netherlands is solid. In object classes such as weaponry, tools, ornaments and unidentifiable objects in funerary contexts (Table 1), iron from HaC onwards swiftly complements (and later replaces; *cf.* Lanting & Van der Plicht 2003, 174) bronze.

However, the increasingly abundant presence of iron artefacts in Early Iron Age urnfield contexts, is not matched by a similarly exhaustive dataset on (local) iron production. Rather, I have argued elsewhere (Arnoldussen & Brusgaard 2015, 117), that evidence for Iron Age primary iron production (*i.e.* smelting) in the Netherlands is as yet absent (*cf.* Brusgaard *et al.* 2015, 359). Smithing, in contrast, appears to be well documented from the Middle Iron Age (*c.* 600-250 cal. BC) onwards: particularly associated finds of *tuyere* or crucible fragments with slag fragments hint at local ironworking (*e.g.* at Velsen-Santpoort, Oss-Ussen and Oss-Schalkskamp; Van Heeringen 1992, 73(157); 75 (159); Schinkel 1998, 91-93; fig. 126; Brusgaard *et al.* 2015, 357).

Most of the local ironworking evidence, however, seems to pertain to the Middle and Late Iron Age periods (Arnoldussen & Brusgaard 2015, 117 table. 1, *cf.* Joosten 2004, 22-25) and it is generally assumed that prior to the Roman Period, no local smelting occurred (*e.g.* De Rijk 2003, 88; Joosten 2004, 30; Van den Broeke 2005, 688; Brusgaard *et al.* 2015, 359). If one wants to investigate

Category	References
Gundlingen swords	Fontijn & Fokkens 2007, 369
socketed axes	Fontijn 2003, 164-165
rings	Desittere 1968, 122; Kortlang 1999, 154; 158; Tol 2000, 110
pins	Fontijn 1995; 2003, App. 7.3; Roymans 1999, 80; Van Wijk <i>et al.</i> 2009, 95-96
unidentifiable grave gifts	Tol 1999, 100; Roymans 1999, Fontijn, Jansen & Van der Vaart 2013, 149-150; Van Wijk <i>et al.</i> 2009, 96

Table 1 Examples of Early Iron Age iron artefacts in the Netherlands.

the transition in ironworking technologies from (A) reworking imported iron billets or bars (e.g. Verhart 2006, 103, Van As 2013, 26, cf. De Rijk 2003; 82-83; 2007, 164, cf. Brusgaard *et al.* 2015, 359) to (B) local iron production (smelting), the ironworking evidence for the Early Iron Age (c. 800-600 cal BC) becomes of particular significance. For Oss-Ussen, six pits dated to the Early Iron Age have yielded slag fragments (Schinkel 1998, 55-56), that are unfortunately not yet studied in detail. For Maastricht – Randwijck, Dijkman (1989, 38) identified a series of slag fragments from an Early to Middle Iron Age ‘horseshoe-shaped feature’ as smelting debris. If this is correct, it would represent one of the earliest indications of local iron production (Brusgaard *et al.* 2015, 359, cf. Van den Broeke 1980, 108; 2012, 287). To investigate this claim, a set of slag fragments from the Maastricht – Randwijck feature has been restudied by the author in 2016.

Context: the Maastricht – Randwyck excavations

The site of Maastricht – Randwyck was excavated between May and September 1984, after local archaeologist B. Knippels discovered pottery sherds on the construction site of the westward expansion of the Maastricht hospital (Dijkman 1989, 9). Subsequent excavation of 1952 m² (under the label MAZI.B) uncovered six larger pits (Fig. 1), yet no smaller features such as postholes – indicating that the later prehistoric surface level had been already disturbed considerably (*ibid.*). The excavations were published in 1989 by Dijkman, but for the present study the original documentation was consulted. The high quality of the excavation reports of that time (in terms of detail and interpretation), as well as the overall exemplary documentation of the project merit a special mentioning here.

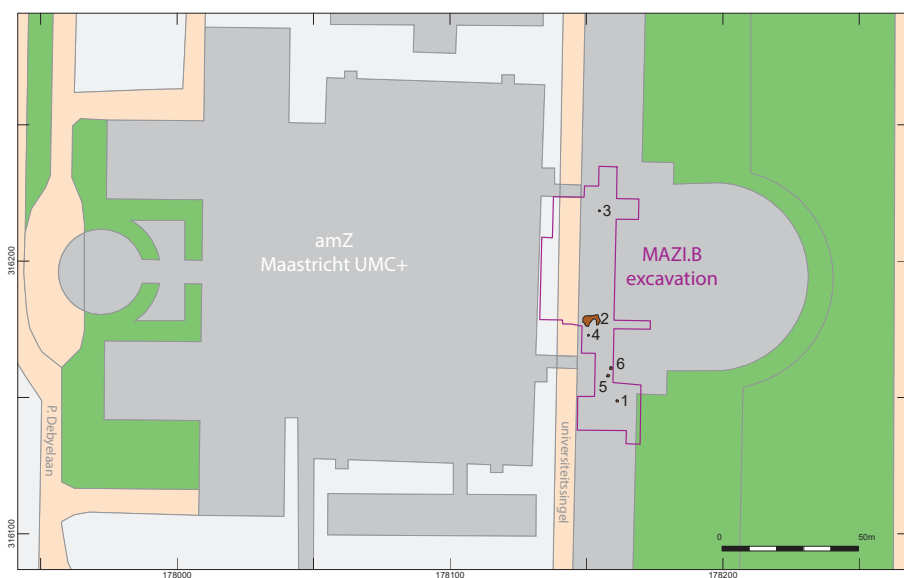


Figure 1. Extent and location of the 1984 MAZI.B (Maastricht Ziekenhuis) excavations in purple outline. The location of Iron Age pits 1 to 6 (brown polygons, black outlines) are indicated as well (after: Dijkman 1989, 11 fig. 3).

A larger feature labelled ‘Pit-cluster 2’ represents the largest feature uncovered, although its central part was cut by a recent tap water trajectory (Dijkman 1989, 9). The features measured 5.6 by 3.6 m in plan and reached between 90 cm (eastern part) to 125 cm (western part) below the 1984 surface level (*loc.cit.*). The lithology of the pit fills is not described, but may be suspected to be silty sand (as the daily reports speak of a ‘*zandige leem*’ matrix). The recent water pipe trench obscures the part of the section that could have shown whether the western and eastern zones were once connected or – more likely considering the steep western profile in section C-C’ (Fig. 2) – once did cross-cut each other.

In the various sections cut across the pit cluster (fig. 2, A-A’, B-B’, C-C’) the distinguished fills are characterised by differences in quantities of burned clay, charcoal and sherds (Dijkman 1989, 38). At the time of excavation, interpretation shifted between an *in situ* oven, an *in situ* smelting furnace and a pit cluster in which refuse from a nearby oven was dumped (daily reports). Due to the (A) absence of burned clay that showed the differential firing temperatures typical of ovens, and (B) irregularity in plan of pit-cluster 2, the latter interpretation was ultimately favoured (daily report 2nd of August 1984; Dijkman 1989, 9).

The various layers of pit cluster 2 contained 1871 pottery fragments, ample (unspecified) quantities of burned clay, three spindle whorl fragments, seven flint artefacts (Dijkman 1989, 72 pl. 26), a copper strip (ring? fibula bow?; fig. 4, nos. 7-8; Dijkman 1989, 73 pl. 27 no. 4), various stones and 146 fragments of burned bone (Dijkman 1989, 12) and ‘tens of’ slag fragments (Dijkman 1989, 12). The original distribution of the slag fragments is difficult to reconstruct. The daily

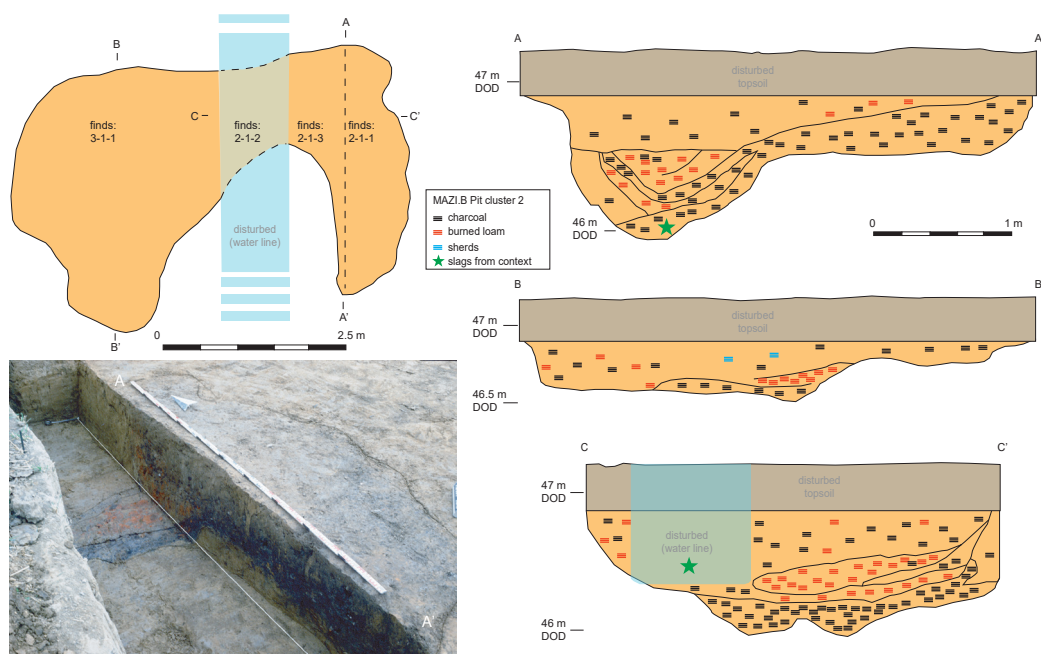


Figure 2. Plan view (top-left) and cross-sections (right, all to the same scale) of pit cluster 2. In the lower left corner a fieldwork photograph of section A-A’ is shown (after: Dijkman 1989, 13 fig. 4; 15 fig. 5 and Maastricht repository (photo).

reports state that several slag fragments were recovered from the water pipe trench backfill (finds nr. 2-1-2) as well as in the undisturbed fill to the east of it ('some slags' : finds nr. 2-1-1). The report of August the 16th states that the fill of 2-1-1 (section A-A') consisted of five layers, of which the lowermost ('e') contained most pottery and 'the slags'.

Dating: the associated finds

In 1984, P. van den Broeke classified the ceramic assemblage as dating to the start of the Middle Iron Age (c. 450-350 cal BC) and noted Marne-style pottery amongst the assemblage (Van den Broeke 1984, 1). The ample quartz-tempered sherds also recovered could, again according to Van den Broeke (*ibid.*), hint at an earlier Iron Age date. In the final report, the ceramic assemblage is assigned a slightly more constricted date-range: 450-400 cal. BC (*La Tène Ancienne* Ib; Dijkman 1989, 26; 36, cf. Lanting & Van der Plicht 2006, 271). If in a general sense the attribution to *La Tène* A is correct, the finds from pit cluster 2 presumably post-date 475 cal. BC and predate 370 cal. BC (Lanting & Van der Plicht 2006, 271; Van den Broeke 2012, 33, cf. Dijkman 1989, 40). The bronze fragment (ring or bow-fibula; fig. 4, nos. 7-8; Dijkman 1989, 73 pl. 27 no. 4) from pit-cluster 2 shows similarities to a bow fibula from Maastricht – Caberg, dated also to *La Tène Ancienne* I (Dijkman 1989, 39).

Composition

Already during fieldwork, the presence of metallic iron in one of the slag fragments was attested by filing into a slag fragment and verifying that the filings stuck to a magnet, and also by noting the interference of a slag fragment on a magnetic compass (daily report 13th of July 1984). During a visit of H. Kars, preliminary visual identifications of chalcopyrite (CuFeS_2), brochantite ($\text{Cu}(\text{SO}_4)(\text{OH})_6$) or bornite (Cu_5FeS_4) were given (daily report 2nd of August 1984). After fieldwork, an unspecified slag fragment was analysed with X-ray fluorescence (XRF) by J.P. de Warrimont at the Dutch State Mines (DSM) and reported to contain primarily iron, with additional occurrence of aluminium and silicon, and traces of manganese, zinc and copper (Fig. 4; Dijkman 1989, 20-21 note 4).

Moreover, four 'half-fist-sized' slag fragments were sent to A. Hauptmann of the Zollern institute in Dortmund (Dijkman 1989, 20; Hauptmann 1989; these are presently not in the Maastricht repository, presumably lost). For two fragments thin-sections were created to study the mineralogical composition, two other fragments were crushed into a powder and analysed with X-ray fluorescence (XRF; Hauptmann 1989, 78-80). Mineralogically, the studied fragments contained mostly fayalite (Fe_2SiO_4), with an addition of Wüstite (FeO) and minor occurrences of magnetite (Fe_3O_4) and goethite ($\alpha\text{-FeO}(\text{OH})$; Hauptmann 1989, 78). The XRF analysis on the two fragments by Hauptmann indicated that the two slags studied contained 69.4-73.3 %wt of iron (oxides), 20.2-23.4 %wt of silicon oxide and 3.4 %wt aluminium oxide (see Hauptmann 1989, 80 table 1; Table 3). Hauptmann argued that the slags represented an initial (smelting) stage of bog iron ores (Dijkman 1989, 39).

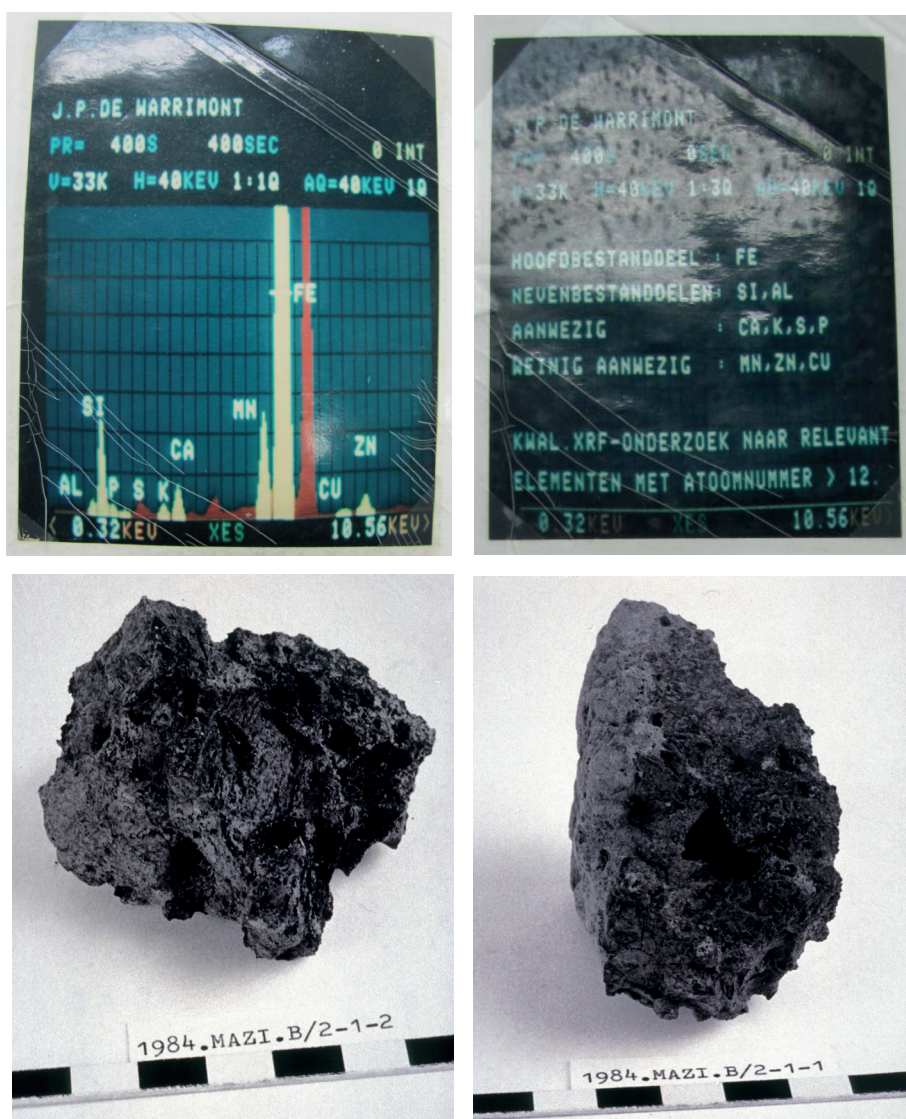


Figure 3. Top: Polaroid documentation of XRF analysis of an unspecified slag fragment by J.-P. de Warrimont (DSM). Bottom: black-and-white photographs of larger slag fragments.

pXRF analysis

A total of eight artefacts from the Maastricht-Randwijck feature were subjected in 2015 to pXRF analysis (Table 2; fig. 4). This was possible due to the kind cooperation of B. van Os, under whose supervision pXRF measurements could be taken at the Cultural Heritage Agency of the Netherlands at Amersfoort. Amongst these eight items are three slag fragments (items 1-3), three fragments of vitreous clay (items 4-6), and two fragments of a bronze item of hemi-circular cross-section (possibly fibula bow or ring fragments; items 7 and 8). Previous analysis of iron slag fragments from Hijken had already shown that the elemental composition

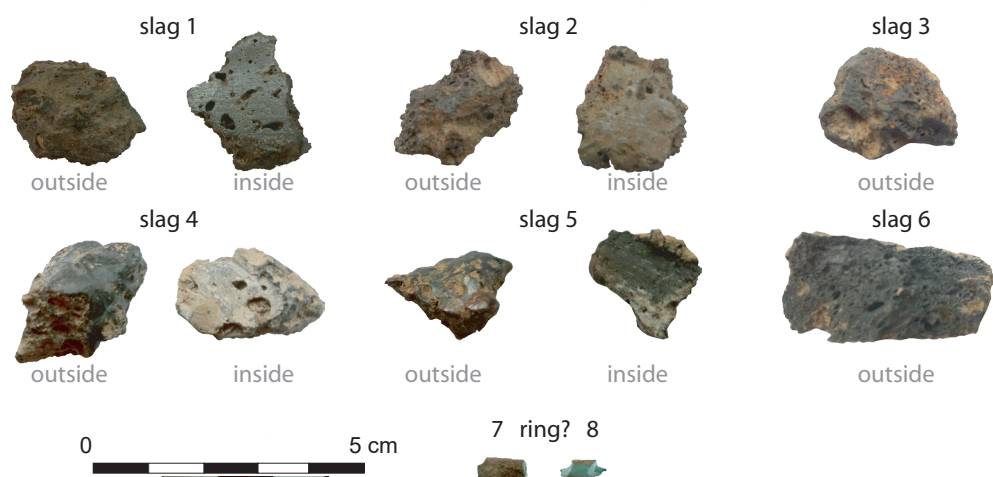


Figure 4. A selection of slag fragments (nos. 1-3; nos. 4-6 proved vitreous clay fragments rather than slags proper; *infra*) and two fragments of a bronze ring (nos. 7-8; or fibula-bow?), all to the same scale.

Measurement	Item	Description	Treatment	Location	Remarks
4842	1	Slag	sawed in half, lightly sanded	inside	
4843	1	Slag	sawed in half	outside	
4844	2	Slag	sawed in half	inside	Charcoal-like textures on outside surface
4845	2	Slag	sawed in half	inside	other half; Charcoal-like textures on outside surface
4846	2	Slag	sawed in half	inside	Charcoal-like textures on outside surface
4847	3	Slag	unpolished	outside	
4848	4	Vitrified	sawed in half	inside	Glassy vitreous material, light weight
4849	5	Vitrified	sawed in half	inside	Glassy vitreous material, light weight
4850	6	Vitrified	none	outside	Porous material, lightweight
4851	7	Fibula/Ring	none	outside	Ring or fibula fragment
4852	8	Fibula/Ring	lightly sanded	outside	Ring or fibula fragment

Table 2 Treatment of samples and locations of pXRF readings.

of outer surface and inner core of plano-convex bottom slag varies considerably (Arnoldussen & Brusgaard 2015, 119). Therefore, for the eight items, a total of eleven measurements was undertaken: slag fragments 1 and 2 were both cut open and measured twice and thrice respectively (Table 2). For items 1 and 8 a reading was taken on a surface area that was lightly cleaned with sanding paper, to reduce the influence of outside corrosion.

The instrument used was a Thermo Scientific NitonXL3t with the measurement of up to 25 simultaneous elements spanning the analytical range between atomic number 16 (sulphur) and 92 (uranium), but that is also capable of detecting light

elements (atomic number 12 (magnesium) to 17 (chlorine)). Measurements were taken in mining mode for a duration of 110 seconds.

Results and interpretation

There is a significant difference in iron content for the objects classified as 'slags' from context 2-1-1 (objects 1-3) versus the items listed as 'slags' from context 3-1-0 (items 4-6). Whereas iron oxides make up 63-72% in weight of the former, the latter range between 4 and 6.5 %wt in iron oxides. The latter group of low-iron slags are also consistently higher in silicium, aluminium and titanium, which suggests that they represent vitrified clay (Dutch: *verglaasde leem*) rather than slags proper. Such fragments could originate from ovens, hearths and smithies, particularly in locations close to the *tuyere* where temperatures rise quickly (*cf.* Teylecote 1987, 292; De Rijk 2007, 119) or on crucibles (Teylecote 1987, 321-322). Two Early Iron Age crucible slags from Meare and Craigywarren (UK) show similarly high values for aluminium- and silicon oxides (Table 3; Teylecote 1987, 322-323 Tab. 8.13). Such values serve as *comparanda* in a general sense (vitrified clay in smithing contexts) rather than as exact parallels to Maastricht items 4-6 (for which morphological arguments as well as compositional arguments (*e.g.* addition of copper and lead from repeated general purpose use) for a use as crucible are lacking). Rather, Maastricht items 4-6 represent parts of an oven, furnace or hearth lining originating from an ironworking smithy.

The elevated values for all oxides – save for iron oxides – for the outside of slag 1 versus its inside, indicates that the silty loam (either as part of the original natural substrate, later fills or as part of the original oven or hearth lining) has been encrusted into the outer corrosion layer of the slag. Removal of the outer oxidation layer of the fibula or ring fragments (measurement 4851 vs. 4852) similarly explain the differences in composition: the highest copper content was measured for the cleaned surface.

Maastricht fragments 1 to 3 contain a high percentage of total iron (64-72 %wt). As experimental smelting has indicated a reduction factor of *c.* 0.2 for iron oxides between ore and smelting slag (Heimann *et al.* 1998, 1032 tab 5 vs. 1033 tab. 8, *cf.* Joosten 2004, 42 tab. 4), Maastricht fragments 1 to 3 could have originally contained between 82 to 92 %wt of iron oxides, which is above the 80% (%wt $\text{Fe}_2\text{O}_3 \sim 56$ %wt Fe^{3+}) deemed necessary for bloomery process in prehistory (Heimann *et al.* 1998, 1026). If one therefore accepts that fragments 1-3 are indeed slags in strictest sense, a comparison to recently similarly analysed Iron Age ironworking slags is beneficial. To this end, two slag fragments from postholes of a well-dated Iron Age house at Hijken – Hijkerveld (*c.* 360-109 cal. BC; Arnoldussen & Brusgaard 2015, 119) and eight slags from Oss – Schalkskamp (*c.* 200-100 cal. BC; Brusgaard *et al.* 2015, 348) have been added to Table 3.

With regards to iron content, the Maastricht slags (63-72%) compare well to the slag inside measurements for Hijken (61-80%) and Oss (52-81%; Table 3). The presence of silicon oxides (25-31% for the Maastricht slags, 16-26% for the Oss slags and 14-24% for the Hijken slags; Table 3) in the slags' inner cores is, in combination with iron oxides, held typical for both smelting and smithing

Site	Measurem.	Item	Remark	Fe2O3	Cu	Sn	Pb	Zn	SiO2	CaO	P2O5	K2O	Al2O3	TiO2
MAZLB (NL), 5th BC	NL-1	Unkn.	Lost fragment	69,40	0,09	n.a.	-	0,00	23,40	-	0,45	0,56	3,38	0,22
MAZLB (NL), 5th BC	NL-2	Unkn.	Lost fragment	73,30	0,08	n.a.	-	-	20,20	-	0,79	1,00	3,43	0,18
MAZLB (NL), 5th BC	4842	1	inside	71,90	-	-	0,02	0,20	20,50	0,57	0,65	0,80	2,75	0,11
MAZLB (NL), 5th BC	4843	1	outside	64,27	0,01	-	0,02	0,15	27,66	0,81	2,09	0,68	9,08	0,15
MAZLB (NL), 5th BC	4844	2	inside	67,59	0,02	-	0,02	0,22	21,74	0,57	0,60	0,44	1,72	0,10
MAZLB (NL), 5th BC	4845	2	inside	69,44	0,04	0,01	0,02	0,24	26,06	0,72	0,72	0,60	3,15	0,15
MAZLB (NL), 5th BC	4846	2	inside	68,38	0,02	0,01	0,02	0,22	25,34	0,65	0,74	0,41	2,37	0,11
MAZLB (NL), 5th BC	4847	3	outside	63,36	0,01	0,01	0,01	0,16	31,28	1,94	2,28	1,54	17,11	0,33
MAZLB (NL), 5th BC	4848	4	inside	6,34	0,02	-	-	-	38,73	1,09	0,39	4,03	15,91	0,85
MAZLB (NL), 5th BC	4849	5	inside	4,21	0,09	0,01	-	-	54,97	1,19	0,33	1,93	6,25	0,68
MAZLB (NL), 5th BC	4850	6	outside	4,49	0,00	-	-	-	48,53	0,26	0,49	4,50	17,04	0,78
MAZLB (NL), 5th BC	4851	7	Fibula/Ring	10,28	6,28	22,47	1,89	0,06	48,88	1,69	1,97	2,53	25,23	1,01
MAZLB (NL), 5th BC	4852	8	Fibula/Ring	2,95	16,84	26,71	3,22	0,06	22,38	1,25	8,47	0,57	6,73	0,24
Oss - SK (NL) 3rd BC	4141	90	outside (green)	9,66	-	-	-	0,00	13,41	2,63	1,31	3,16	2,38	0,17
Oss - SK (NL) 3rd BC	4142	90	inside (black)	76,45	0,01	-	0,01	-	26,82	0,55	0,51	0,26	1,02	0,02
Oss - SK (NL) 3rd BC	4143	90	inside (yellow)	49,19	-	0,01	0,00	-	46,81	0,78	0,48	1,10	1,47	0,05
Oss - SK (NL) 3rd BC	4144	43	inside	66,97	-	-	0,01	0,01	16,27	1,76	0,43	0,84	1,49	0,00
Oss - SK (NL) 3rd BC	4145	121	inside	80,94	-	0,01	0,02	-	18,05	2,69	1,04	0,92	1,77	-
Oss - SK (NL) 3rd BC	4146	4	inside	52,45	0,01	0,01	0,01	0,01	10,84	1,91	0,60	0,79	1,91	0,11
Oss - SK (NL) 3rd BC	4147	123	inside	72,79	-	-	0,02	-	23,13	3,35	1,13	1,19	0,94	0,04
Oss - SK (NL) 3rd BC	4148	123	on 'rusty' spot	54,52	0,01	-	0,01	0,01	11,62	0,72	2,20	0,22	1,05	0,01
Oss - SK (NL) 3rd BC	4149	19	inside	73,79	0,01	-	0,01	-	28,26	1,03	0,35	0,95	2,16	0,03
Hijken - HV (NL) 4-2nd BC	4818	57	inside	79,30	0,03	0,01	0,02	-	22,94	1,90	1,54	1,19	0,96	0,02
Hijken - HV (NL) 4-2nd BC	4819	57	inside	64,88	0,02	-	0,01	-	14,71	2,73	1,17	1,84	0,91	0,05
Hijken - HV (NL) 4-2nd BC	4820	57	inside	61,44	0,01	0,01	0,01	-	14,44	2,87	1,30	1,99	0,86	0,07
Hijken - HV (NL) 4-2nd BC	4821	57	inside	80,27	0,02	0,01	0,03	-	23,91	1,94	1,29	1,37	1,32	0,02
Hijken - HV (NL) 4-2nd BC	4822	57	outside	16,79	0,02	-	0,00	0,00	30,42	2,91	4,02	4,55	1,78	0,22
Hijken - HV (NL) 4-2nd BC	3375	57	outside	71,11	0,47	0,13	0,01	0,01	10,95	0,50	8,35	0,33	13,71	0,21
Hijken - HV (NL) 4-2nd BC	3374	52	inside	72,80	0,21	0,13	0,01	-	18,17	2,15	3,20	1,25	5,94	0,13
Hijken - HV (NL) 4-2nd BC	3373	52	inside	80,18	0,24	0,02	0,00	-	17,53	1,50	1,69	1,16	6,22	0,03
Noreia (AT) 7th BC	1		Bloomery slag	72,55					15,95	2,75	0,40		1,47	
Noreia (AT) 5th BC	2		Bloomery slag	68,01					24,48	1,99	0,15		2,54	
Noreia (AT) 3-1st BC	3		Bloomery slag	66,05					20,72	3,85	0,40		1,96	
Czechos. (CZ) 3-1st BC	1		Bloomery slag	71,71					18,37	1,73	1,83		0,60	
Haithabu (DK) 8-11th AD	1		Smithing slag	62,33					n.a.	1,99	tr		4,58	
Meare (UK), EIA	1		Crucible slag	7,30	2,00		tr		66,80	6,20	-	-	14,50	tr
Craigywarren (UK), EIA	1		Crucible slag	11,20	1,00		0,20		46,20	12,80	1,20	4,40	10,60	tr

Table 3 Analysis results for the composition of the Maastricht – Randwyck slags (after: Hauptmann 1989, 80 tab. 1) and several national (Hijken, Oss) and international comparanda.

slags (Tylecote 1987, 312; Serneels & Perret 2003; Selskienė 2007, 23; Brusgaard *et al.* 2015, 355). In some occasions, the fact that smithing slags were formed in multi-purpose hoards, means that they picked-up quantities of non-ferrous metals (particularly copper, lead and tin) not typical for primary smelting slags (Tylecote 1987, 316; Arnoldussen & De Vries 2014, 119-120). Tin and copper do

MnO	Na2O	S	Cl	Cr	Zr	Sr	Rb	Ba	V	Mg	As	Bal	Reference
1,61	0,37	0,20	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-	n.a.	n.a.	Hauptmann 1989
0,51	0,85	-	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-	n.a.	n.a.	Hauptmann 1989
1,55	n.a.	0,19	336,51	695,24	267,11	21,24	34,57	484,30	239,47	-	-	1,17	This study
1,44	n.a.	0,20	317,04	613,94	158,95	26,31	34,77	508,16	196,90	-	-	-6,18	This study
1,37	n.a.	0,15	810,17	769,37	101,52	18,77	12,65	469,92	221,66	15035,55	-	5,88	This study
1,30	n.a.	0,18	787,88	564,14	131,15	26,55	20,91	365,27	183,89	-	-	-2,13	This study
1,35	n.a.	0,18	762,60	626,73	136,87	15,99	10,75	452,52	238,00	-	-	0,64	This study
1,36	n.a.	0,23	268,35	566,62	248,88	80,41	39,91	686,98	204,51	-	-	-19,20	This study
0,06	n.a.	0,22	-	200,97	208,11	191,95	210,08	611,43	203,30	-	-	32,60	This study
0,02	n.a.	0,65	-	158,30	386,25	81,71	91,69	282,33	73,01	-	13,56	30,42	This study
0,02	n.a.	0,29	-	221,70	173,53	138,86	259,25	552,14	118,86	-	4,72	23,89	This study
0,14	n.a.	0,36	-	405,04	130,79	111,62	101,71	-	230,45	-	-	8,28	This study
-	n.a.	1,73	-	126,53	-	60,97	39,64	-	-	-	2298,66	57,38	This study
0,18	n.a.	0,20	-	139,31	174,60	173,68	150,93	513,06	55,94	-	10,47	67,10	Brusgaard et al. 2015
-	n.a.	0,07	628,99	509,19	99,42	21,72	-	263,83	153,83	-	-	-5,66	Brusgaard et al. 2015
0,03	n.a.	0,11	447,62	407,95	157,13	41,71	30,54	434,78	93,83	-	-	0,07	Brusgaard et al. 2015
0,11	n.a.	0,11	739,51	582,55	63,30	87,45	35,85	622,55	133,96	-	-	12,12	Brusgaard et al. 2015
0,07	n.a.	0,14	793,07	675,64	53,43	84,79	34,79	527,86	176,84	-	-	-5,45	Brusgaard et al. 2015
0,10	n.a.	0,16	606,94	472,86	131,31	79,08	66,46	585,72	155,95	-	-	31,28	Brusgaard et al. 2015
0,10	n.a.	0,39	701,89	464,56	78,79	89,80	55,65	381,47	159,32	-	-	-2,67	Brusgaard et al. 2015
0,14	n.a.	0,13	341,19	305,55	62,79	36,18	35,44	463,64	92,32	-	-	29,51	Brusgaard et al. 2015
0,06	n.a.	0,24	681,80	596,65	76,51	48,55	40,80	407,10	185,40	-	-	-6,64	Brusgaard et al. 2015
0,08	n.a.	0,14	171,12	599,29	73,59	73,61	42,81	539,60	159,03	-	-	-7,93	Arnoldussen & Brusgaard 2015
0,09	n.a.	0,16	892,23	548,36	105,73	114,13	39,14	580,59	140,72	-	-	13,62	Arnoldussen & Brusgaard 2015
0,10	n.a.	0,19	883,15	528,37	115,78	114,87	56,18	371,48	140,60	-	-	16,94	Arnoldussen & Brusgaard 2015
0,08	n.a.	0,13	259,87	642,14	73,31	77,54	35,52	532,15	176,56	-	-	-10,20	Arnoldussen & Brusgaard 2015
0,16	n.a.	0,40	65,91	200,20	169,49	181,33	83,63	587,68	68,75	-	20,85	39,16	Arnoldussen & Brusgaard 2015
0,03	n.a.	0,34	426,08	538,00	103,83	42,87	-	559,63	211,06	-	71,54	-5,20	Arnoldussen & Brusgaard 2015
0,07	n.a.	0,23	191,48	482,44	98,49	97,24	30,37	470,12	181,47	24849,77	36,65	-3,71	Arnoldussen & Brusgaard 2015
0,04	n.a.	0,21	148,67	712,09	65,84	80,90	40,08	686,52	-	27704,09	-	-8,34	Arnoldussen & Brusgaard 2015
1,29										9000,00			Teylecote 1987, 314; Neumann 1954
2,35										143000,00			Teylecote 1987, 314; Neumann 1954
2,38										18500,00			Teylecote 1987, 314; Neumann 1954
0,46										n.a.			Teylecote 1987, 314; Neumann 1954
tr										1800,00			Teylecote 1987, 319; Pleiner et al. 1971
-	-	0,30											Teylecote 1987, 322-33 Tab. 8.13
-	4,40	0,40									5000,00		Teylecote 1987, 322-33 Tab. 8.13

not surpass 0.4 %wt on the inside readings of Maastricht slags 1 to 3 (Table 3), indicating that they originated from a pyrotechnical process that focussed on iron exclusively (unlike Hijken slag v57, with 0,47 %wt copper, and the Meare crucible slag; Table 3). In comparison to the Hijken and Oss slags, the Maastricht slags are consistently high in zinc (0.2-0.24%wt versus < 0.01 %wt) and manganese oxide (1.3-1.55 %wt versus < 0.18%wt).

Zinc is an uncommon element of ironworking slags, yet in sparse quantities (< 0,02 %wt) it has been documented in smithing slags from Oss and Hijken (Table 3) as well as in modern limonite ores (Heimann *et al.* 1998, 1023 tab. 1; Joosten 2004, 56 tab. 13) and rattlestone ores (Dutch: *klappersteen*; Joosten 2004, 79 tab. 20; 106 tab. 33). For the Maastricht fragments, the more substantial presence of zinc (0.2-0.24%wt) in items 1 to 3 and its absence (below detection limit) in items 4-6 again confirms their different nature (*i.e.* ironworking slags versus vitrified clay) of items 1-3 versus 4-6. Possibly, increased levels of aluminium, nickel and zinc hint at incorporation of clayey elements (*cf.* Heimann *et al.* 1998, 1022-1023) through either the ore (weathering/transport of clayey natural embedding of bog ore), or through the smelting or smithing process (incorporation of oven, hearth, flux, or crucible material), but for Maastricht items 1 to 3 moderate values for clay proxies such as aluminium, calcium and titanium (Table 3) argue against such an interpretation. Most probably, the zinc observed in Maastricht items 1 to 3 is related to contact with wood ash, which can be rich in zinc (*e.g.* up to 260 mg/kg; Joosten 2004, 43-44).

Manganese can be a part of Limonitic bog iron ores, that may contain several percent manganese Mn (in rare cases up to 20%; *e.g.* Heimann *et al.* 1998, 1022 fig. 4). Generally, the amount of manganese is reduced in the smithing stage compared to the smelting stage, but occurrences of manganese oxide in the range of 0.2 to 2.6 %wt in smithing slags have been reported (Selskienė 2007, 24; Heimann *et al.* 1998, 1027). Smelting experiments suggest an increase in manganese oxide concentration of factor 5 between ore and smelting slag (Heimann *et al.* 1998, 1032 tab 5 vs. 1033 tab. 8, *cf.* Coustures *et al.* 2003, 603 tab. 1), and a reduction of factor 0.3 from smelting to smithing slag (Selskienė 2007, 24). The manganese content of the Maastricht slags could therefore imply ores with an original manganese oxide content of 0.3 %wt (if the Maastricht slags are smelting slags) or 0.43 %wt (if the Maastricht slags are smithing slags), which aligns with documented values of up to 5.8 %wt manganese oxide in Dutch bog iron ores (Reinders 1896, 10; Tilley 1936, 341; Joosten 2004, 42 tab. 4; 56 tab. 13) and rattlestone ores (Joosten 2004, 79 tab. 20; 106 tab. 33).

The presence of (otherwise soluble) chlorine in Maastricht items 1-3 is most likely related to the formation of akaganeite ($(\text{Fe}^{3+}\text{Ni}^{2+})_8(\text{OH},\text{O})_{16}\text{Cl}_{1.25} \cdot n\text{H}_2\text{O}$) in the ironworking slags. Akaganeite is an iron/nickel hydroxide-chloride mineral formed by the weathering of pyrrhotite (iron sulphide oxide) in the slags. Chlorine therefore *is* found with all ironworking slag with Fe %wt above 50% (at Maastricht, Hijken and Oss; Table 3). Measurement 4822 (the outside of Hijken slag v.57) moreover shows the strong correlation between (in this case, reduced) iron content and chlorine presence.

Conclusions: smelting or smithing slags?

As a first conclusion, pXRF analysis has clearly shown that Maastricht items 1 to 3 and 4 to 6 respectively have markedly different compositions. Fragments 1 to 3 have a composition that is typical for ironworking slags, although their exact interpretation (smelting or smithing slag) merits additional discussion below.

Fragments 4 to 6 have a low iron content, higher aluminium and potassium, and no discernible zinc and chlorine, which suggest that they are vitrified clay elements rather than ironworking slags proper. This being said, it is evident that during ironworking there are ample opportunities for such vitrification of clay (*e.g.* clay linings of ovens, hearths, *tuyeres*, or crucibles) to occur. It is consequently not possible to confirm or refute a relation to ironworking for fragments 4-6. Fragments 7-8 are part of a, possibly Late Iron Age, bronze (high copper, high tin) artefact incorporated into the pit cluster's fill. Based on their high iron and silicon oxide content and porous nature, Maastricht items 1-3 *do* appear to be ironworking slags in the strictest sense.

Due to innate heterogeneity (*cf.* Joosten 2004, 17), telling smelting slags apart from smithing slags remains difficult (Tylecote 1987, 318; Joosten 2004, 18; Selskienė 2007, 24). In distinguishing smelting from smithing slags, their morphological characteristics can hold vital clues (Tylecote 1987, 310-311; De Rijk 2003, 26-30; Joosten 2004, 16-17; Selskienė 2007, 22). Unfortunately, none of the preserved slag fragments of Maastricht is large enough to have preserved such morphological clues (*e.g.* flow structures, imprints).

Heimann (*et al.* 1998, 1025) have argued that zinc, nickel and copper migrate to the iron sponge during smelting (as do cobalt and arsenic; Joosten 2004, 11; Navasaitis, Selskienė & Žaldarys 2010, 115), which accounts for discrepancies between high ore/smelting slag values and low smithing slag values. Relatively high values for zinc do apply to Maastricht slags 1 to 3, yet their levels of nickel and copper are matched by those of confirmed smithing slags from Oss and Hijken (Table 3).

Dutch bog iron ores may contain up to 8.8 %wt of phosphorus pentoxide (P_2O_5 ; Joosten 2004, 42 tab. 4; 43; 56 tab. 13; 117). Moreover, in the process of smelting a significant uptake of phosphorus occurs (derived mainly from the charcoal, that can range from 4.2-16.7 %wt P_2O_5 ; Navasaitis, Selskienė & Žaldarys 2010, 113; Tylecote 1962, 348; Buchwald & Wivel 1998, 82, but see Joosten 2004, 43 tab. 5 for much lower values), amounting to values above 2% P_2O_5 (Tylecote 1987, 310-312; Joosten 2004, 57 tab. 14; Selskienė 2007, 24) and up to 5 %wt P_2O_5 ; Navasaitis, Selskienė & Žaldarys 2010, 115 tab. 1) in smelting slags. None of the Maastricht items contain values above 0.75 %wt of P_2O_5 on the slag's insides, which suggest an interpretation as smithing, rather than smelting slags (*cf.* De Rijk 2003, 32). On the outside of Maastricht slag item 2, a wood-structure has been preserved through limonisation – suggesting contact with wood or charcoal – but such impressions are unfortunately not specific for smelting or smithing slags (De Rijk 2003, 28-29).

With respect to their manganese content, De Rijk (2003, 32) argues that in smithing slags, values of manganese oxide above 0.5 %wt are unknown (following Fröhlich *et al.* 1987, 60; McDonnell 1988, 288). For the Maastricht items 1 to 3, I have however argued that the observed values align well with manganese oxide values established for known Dutch bog and rattlestone iron ores.

In conclusion, there is insufficient evidence to suggest Early Iron Age *smelting* of iron at Maastricht – Randwyck. First, with regard to the dating of the context from which the ironworking debris was recovered, a dating in the later part of the

5th and start of the 4th century BC seems most likely (*i.e.* post-dating the Early Iron Age of 800-600 cal. BC). Second, whereas the recovered remains unambiguously indicate ironworking, *smelting* could not be proven, nor is there evidence that the pit cluster 2 accurately relates to the location of such an ironworking workshop or smithy. Rather, in pit cluster 2 an assemblage was recovered that fits best our present knowledge of smithing processes, but pit-cluster 2 may in itself have served altogether primary functions (of which a possible kiln location merits more study). From pit-cluster 2, an assemblage was recovered that could very well represent what remained of a cleaned, cleared or dismantled ironworking workshop (*i.e.* charcoal, burned clay, smithing slags) was deposited. There are, however, insufficient clues to suggest that the pit-cluster itself was the locus of such activities. Ideally, the pit's lowermost (primary) fill would have been investigated for the presence of hammerscale fragments to pin-point metalworking to that particular feature (as hammerscale is generally too small to recover and gets trodden into smithy workshop floors). The Maastricht metalworking debris may therefore also have been cleared from elsewhere and deposited in the in-fill of pit-cluster 2 (*cf.* Brusgaard *et al.* 2015). Thus, whereas smelting (*i.e.* primary processing of ores) could not be proven, metalworking (smithing) is well documented – albeit that its exact location remains unknown. Nevertheless, in the 5th century BC, certain Maastricht individuals had acquired both base materials (bloom and/or billets) and knowledge to craft iron object. In hindsight, retention of the largest slag fragments (now missing) and scrutiny for hammerscale in the pit's sediments, could have enriched our view of the types and variability of tasks undertaken in the smithy from which debris ended-up in Maastricht pit cluster 2. While it turned out that Maastricht – Randwyck (MAZI.B) is not 'the smoking gun' for the Dutch earliest iron production, it still represents an important stepping stone into our narratives of metalworking craft in the Netherlands.

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METAALTIJDEN 4

BIJDRAGEN IN DE STUDIE VAN DE METAALTIJDEN



REDACTIE:

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STICHTING METAALTIJDENONDERZOEK NEDERLAND